Ultrafast Lasers for Accelerator Timing Applications

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Outline

- Development of ultrafast laser
- Accelerator applications
  - Stable timing and synchronization
  - High-precision time-of-flight
  - Technique primarily used for FEL accelerators
- Ultra-stable DAQ sampling system?

Ultrafast Lasers

Some key steps to development of ultrafast laser

- Development of wide-bandwidth gain materials
  - Ti:saphire, Erbium-doped and Ytterbium-doped fibers
- Advent of passive mode-locking over active
  - Allows for femtosecond laser pulses
- Rapid growth of diode lasers
  - Stable pumping → stable laser performance
  - Increased pumping efficiency
- Commercial availability of key components/systems
  - Much driven by the telecommunication industry
  - Ultrafast Erbium (1550 nm) fiber lasers everywhere

Were Lasers are Today

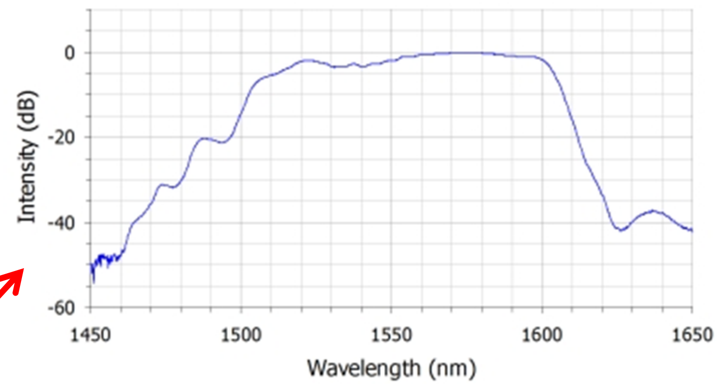
- High peak power, PW
- High average power, kW
- High energy, MJ
- Ultrashort pulses, fs/sub-fs
- IR ~ UV/deep UV/Soft x-ray
- High stability/turn key, 24/7 operation
- Compact, suitcase size/100 W
- Broad commercial availability

But not all in one package!

Typical Commercial Fiber Laser

Er-doped femtosecond oscillator and optional amplifier at 100 MHz repetition rate

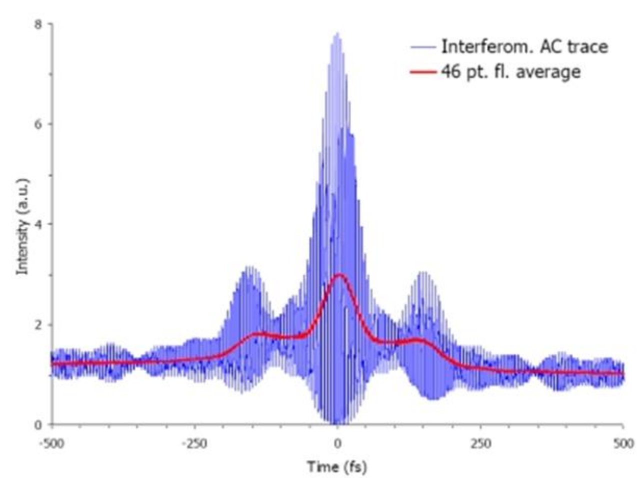
C-Fiber: Spectrum of the fiber-coupled output port (LC/APC)



Optical output power: 16 mW, spectral width: 59 nm @ 3 dB
(Data source: System No. 9190, Test Data Sheet)

- Broad spectral bandwidth: ~ 60 nm
- *pulse length <90 fs*
- average output power >250 mW @ 100 MHz
- synchronization to external clock signal
  - *Low phase jitter*
- *high stability, reliable operation*
- truly turnkey operation by self-starting mode-locking mechanism
- ~ $30-60K and dropping

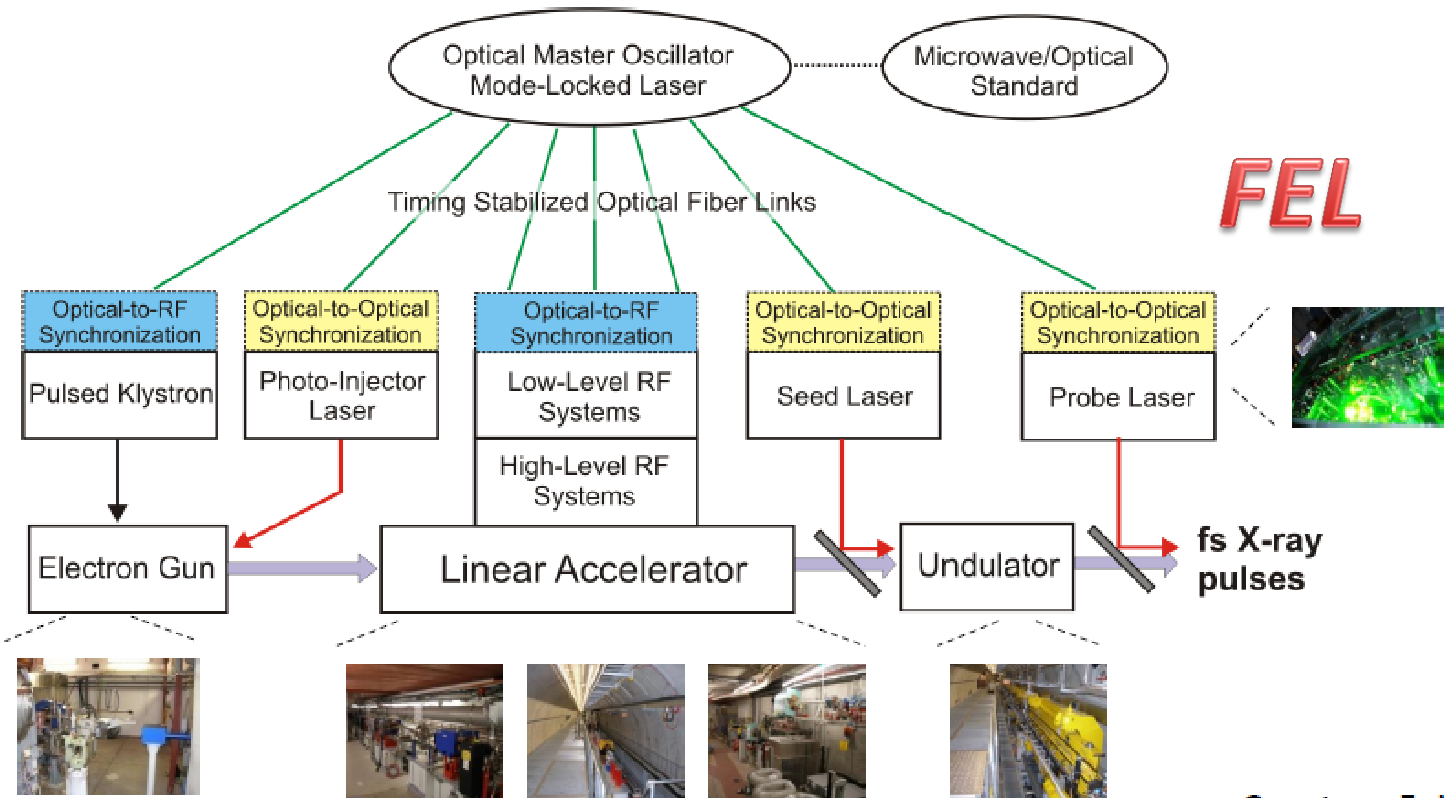
C-Fiber A: Autocorrelation



Optical output power: 169 nm, autocorrelation width: 87 fs, calculated pulse width: 62 fs
(Data source: System No. 9162, Test Data Sheet)

Laser and Synchronization

- High precision timing and sych. with lasers/optical technique
- Achieved <20fs jitter on 100s meter scale



Courtesy F. Kartner

S. ZHANG, BIW'2012, Newport News, VA

Jefferson Lab

Courtesy of Shukui Zhang(Jefferson Lab)

DESY Femtosecond Resolution Bunch Arrival Time Monitor for FELs*

Optical synchronization systems,

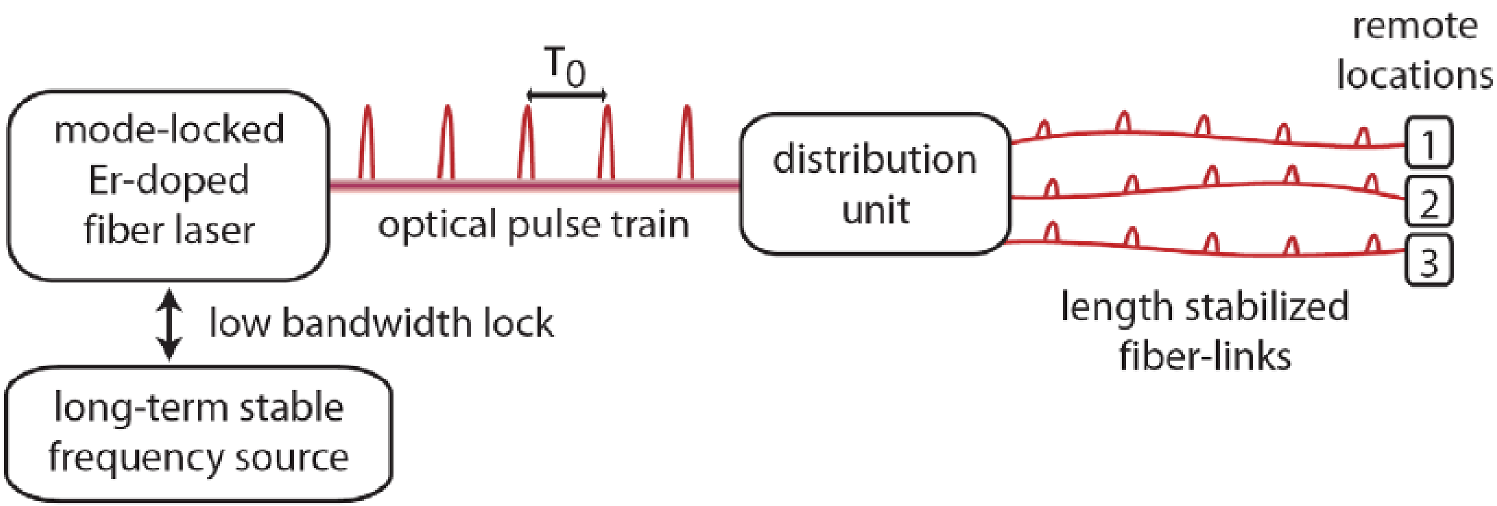
- Based on mode-locked fiber lasers
- Pulses are distributed over length stabilized fiber links
- Provide femtosecond stability for the next generation of free electron lasers.

Bunch Arrival Monitor (BAM)

- Based on bunch-induced signal in a broad-band beam pick-up
- Invokes an amplitude modulation in a train of short laser pulses
- Laser pulses detected with a photo diode and a fast ADC

**Courtesy of Florian Loehl (DESY & CLASSE)*

Optical Synchronization System



- Timing information is encoded in precise laser repetition frequency.
- Non-linear optical methods are used for high resolution timing measurements.

Scheme initially proposed by F.X. Kaertner Group, MIT

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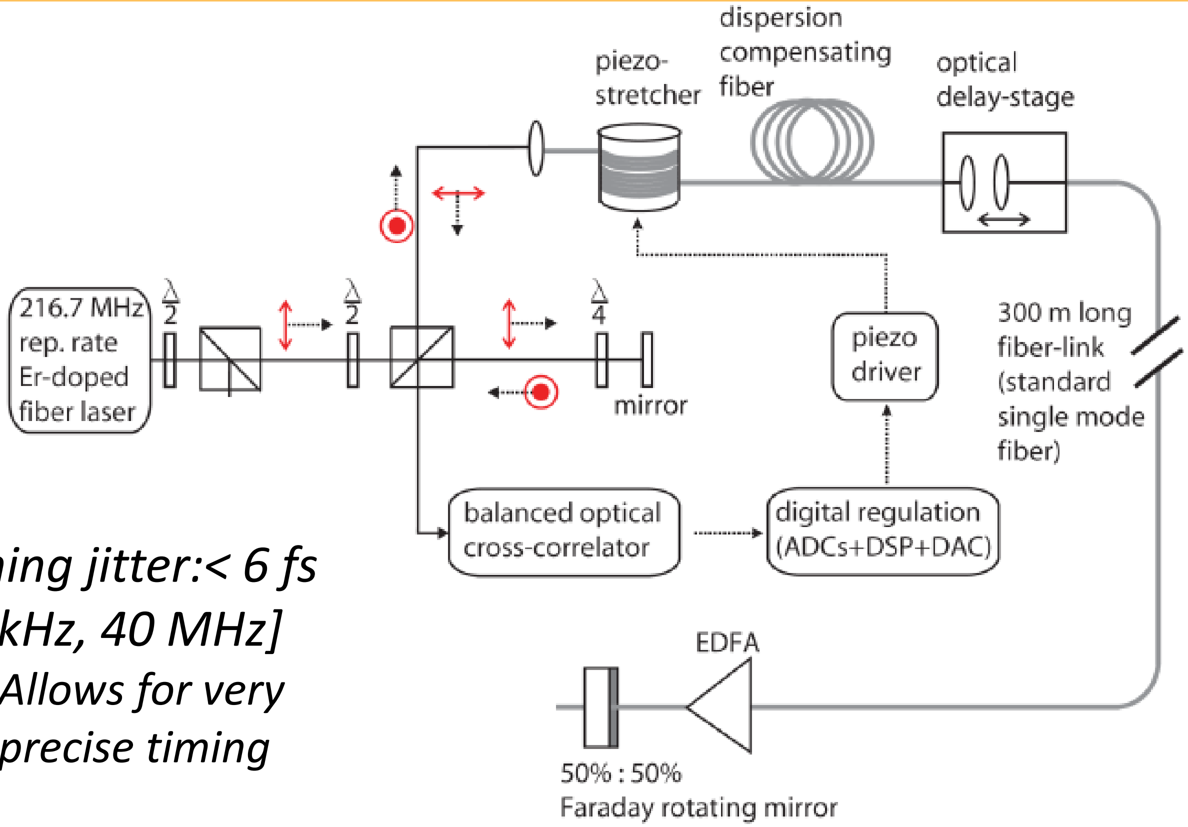
Florian Löhl, Cornell University

Courtesy of Florian Loehl (DESY & CLASSE)

Fiber Length Stabilization



Timing jitter:< 6 fs [10kHz, 40 MHz]

- *Allows for very precise timing*

Note: Berkley has developed a fs timing system based on CW laser

In collaboration with MIT

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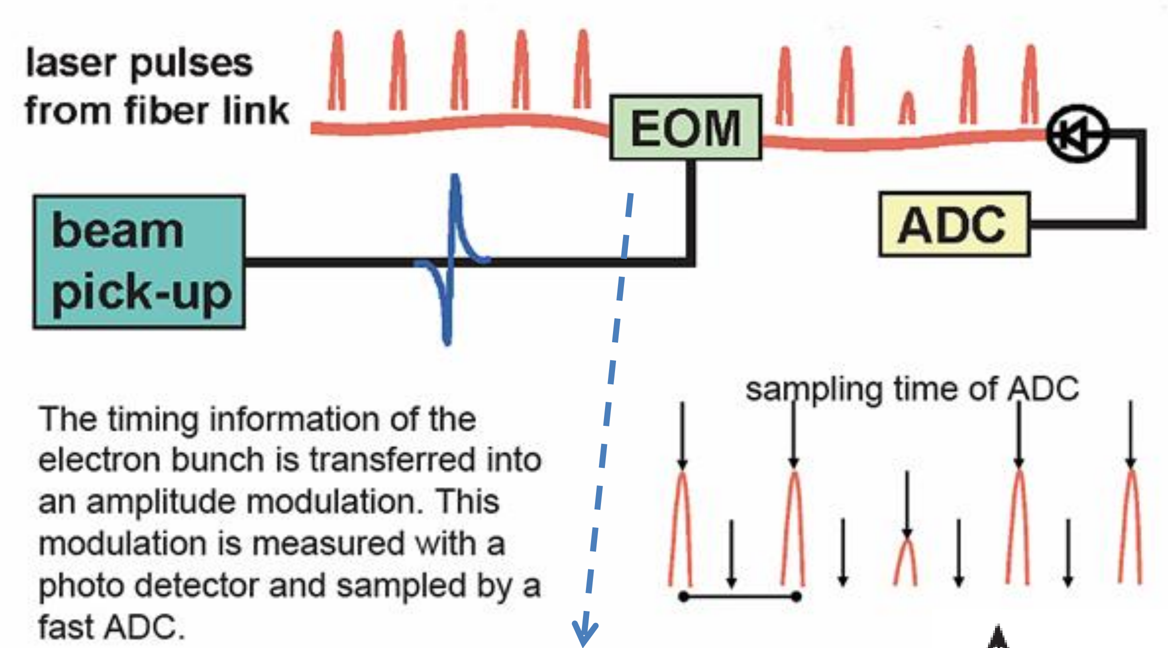
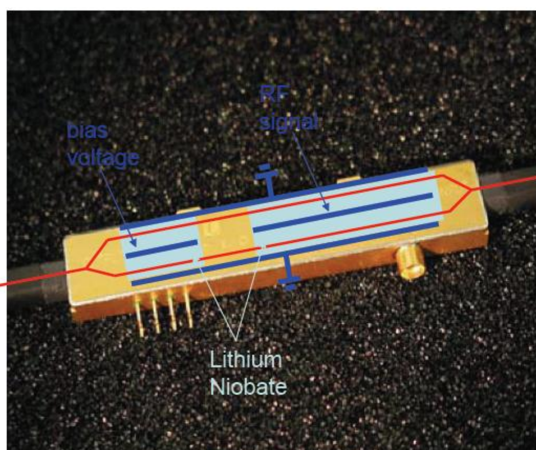
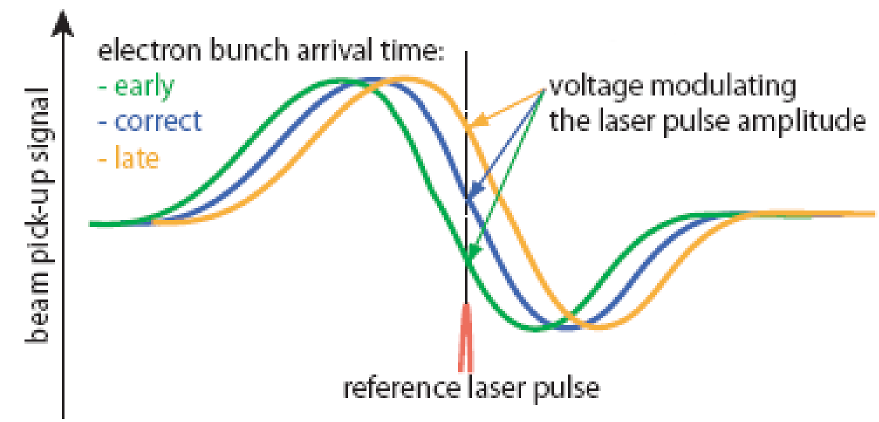
Principle of Bunch Arrival Monitor



A laser pulse samples the zero-crossing of a beam induced pick-up signal.

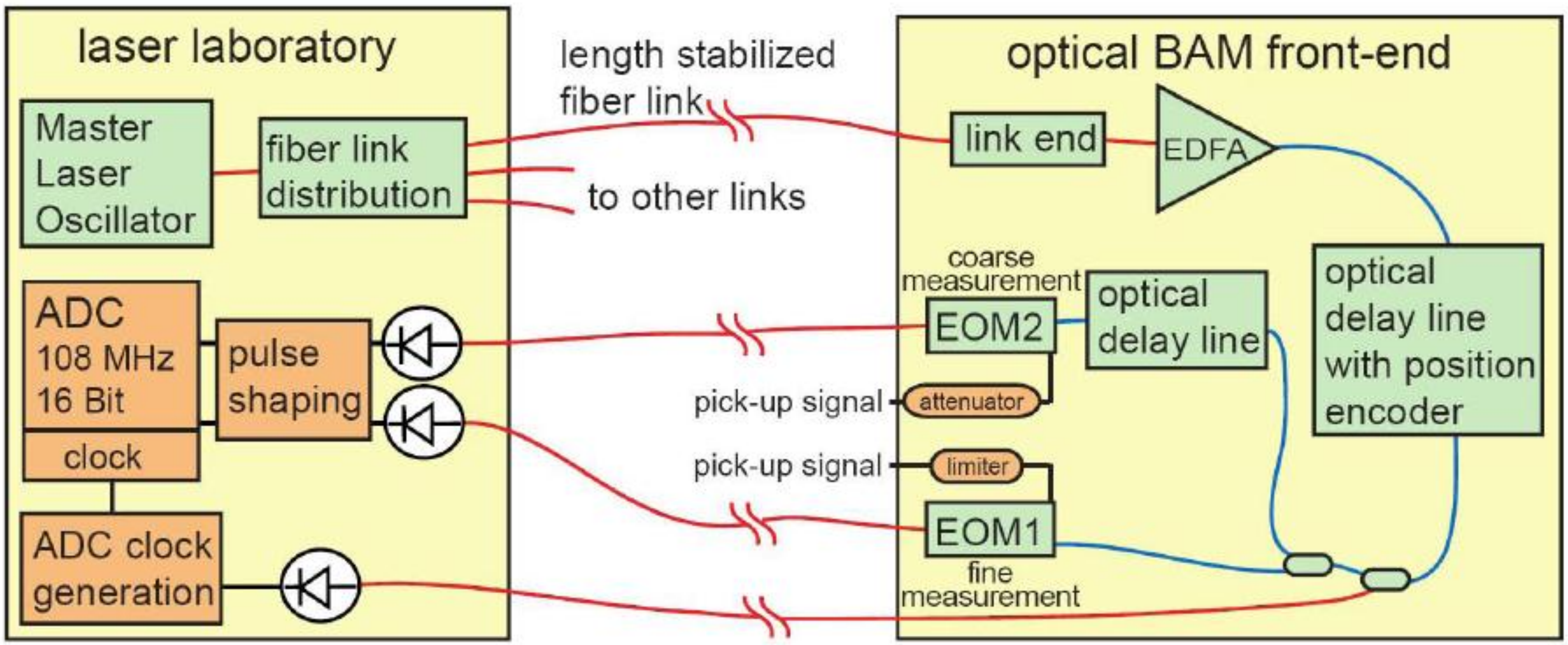


Commercially available with bandwidths up to 40 GHz

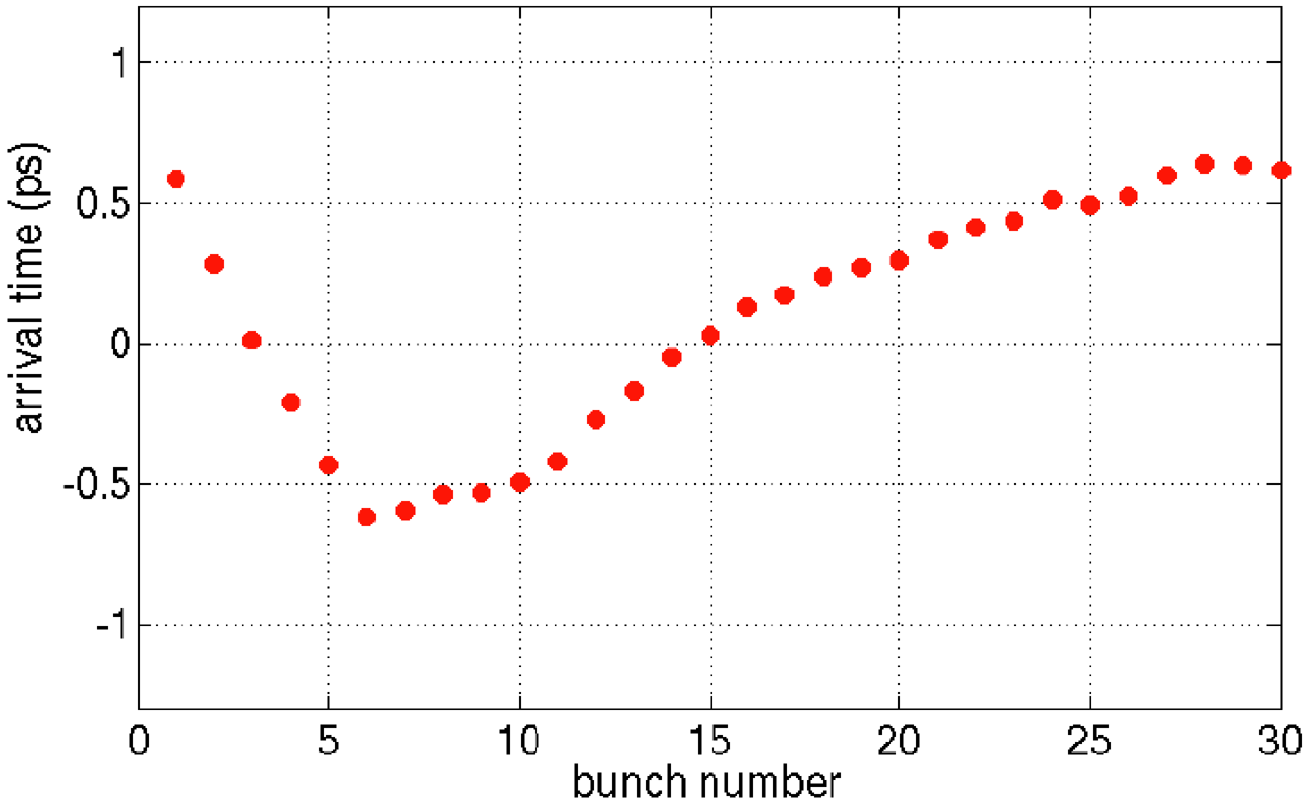


Courtesy of Florian Loehl (DESY & CLASSE)

Bunch Arrival Time Monitor (BAM) Schematic Setup



Arrival-time along the FLASH Bunch Train



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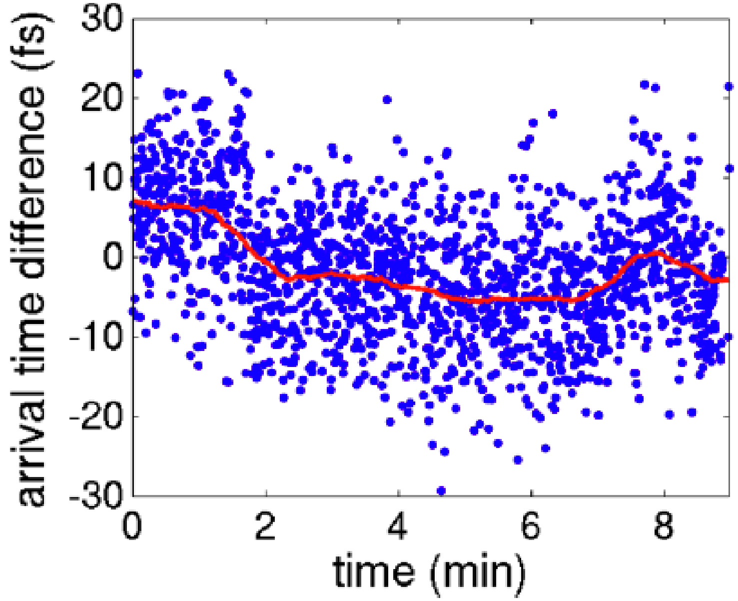
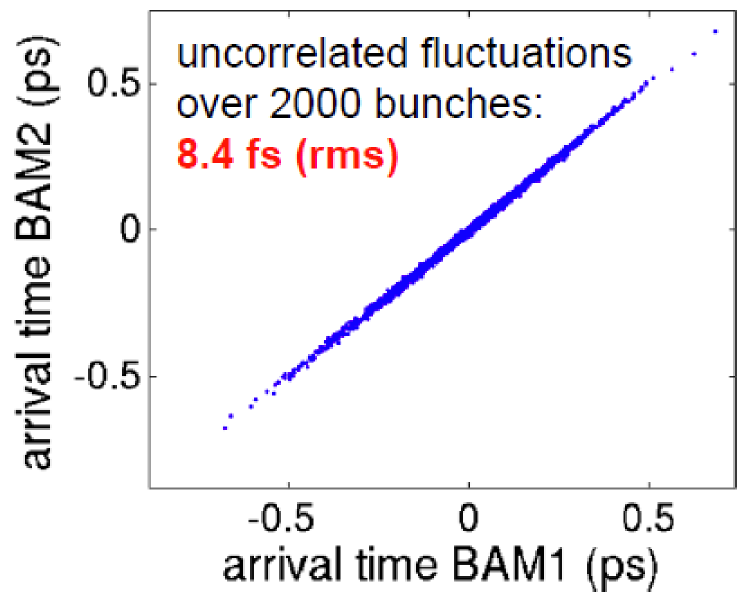
Measurement of the BAM resolution





Difference between both measurements caused by:

- BAM resolution
- Stability of fiber-links
- Fast laser timing jitter (~3 MHz – 108 MHz)

Stability of a complete measurement chain: **< 6 fs (rms)**

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Florian Löhl, Cornell University

Courtesy of Florian Loehl (DESY & CLASSE)

2010 BIW FARADAY CUP AWARD

2012 award (in its 11th edition) was assigned to Kirsten Hacker (DESY) and Dr. Florian Loehl (CLASSE) for *Femotosecond Resolution Beam Arrival Time Monitor*.

Generic High-Stability Digitizer?

Does Project X (either accelerator or experiments) have the need to synchronize/measure events to the ~ 10 fs level?

- Can we make a system similar to low-cost version of the DESY stabilized timing and BAM system?
  - Use a single clock source with many stabilized fiber links
  - Use electro-optic modulation (EOM) to sample beam and/or experimental signals
    - May be able to sample at up to a few GHz with ~10's of fs phase stability
    - Cost would primarily in multiple EOMs (~$2K to $5K each)
    - Possibly integrate multiple EOMs into single substrate (R&D)

Summary

- Laser technology has advanced dramatically in recent years
- Stability and small pulse width of ultrafast lasers are being applied to accelerator systems
- Ultrafast laser are allowing measurement of events in the femtosecond regime
- Can we use this ultrafast timing technology for Project X?
  - Develop a generic ultra-stable digitizer?